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FUEL ASSEMBLY

Cross-Reference to Related Application:

This application is a continuation of copending International Application No. PCT/EP02/01546, filed February 14, 2002, which designated the United States and which was not published in English.

Background of the Invention:

Field of the Invention:

The invention relates to a fuel assembly comprising nuclear fuel with a multiplicity of fuel rods guided through spacers for use in a nuclear reactor in a nuclear power plant. A passage is formed between the fuel rods for a flow of coolant, and at least one spacer carries a vane which imparts a swirl impulse to the flow of coolant.

In a nuclear reactor of a nuclear power plant, the nuclear fuel is usually disposed in hermetically sealed fuel rods. Each fuel rod is several meters long and has a cladding tube with a diameter of approximately 11 mm and a wall thickness of approximately 1 mm. Each cladding tube is filled with nuclear fuel which has been pressed into pellets over virtually its entire length. Usually, approximately 80 to 300 fuel rods,

depending on the type of reactor, are combined in a fuel assembly.

Fuel assemblies which are intended for use in boiling water reactors are provided with a so-called fuel assembly channel, which laterally surrounds the entire fuel assembly structure and is open at the bottom and at the top. Within the fuel assembly channel, the fuel rods are laterally supported by means of spacers, which for their part bear against the walls of the fuel assembly channel from the inside. Often, some of the possible fuel rod positions are fitted with a coolant tube instead of fuel rods. The fuel rods themselves form a multiplicity of cooling passages which extend over the entire length of the fuel assemblies and in which the spacers inevitably form particular flow resistances.

An assembly of this type is described in the commonly assigned U.S. Patent No. 5,327,472 and European patent EP 0 517 750 B1. In that prior art configuration, the spacers bear vanes which are bent into the cooling passages formed by fuel rods in such a manner that they produce a swirl in the stream of coolant flowing through the cooling passage in question. A rotary motion of the stream of coolant about its vertical axis which is imposed by the swirl on the one hand - in particular in the upper region of the fuel assembly - is responsible for good wetting of the fuel rods with liquid coolant and on the other

hand is also responsible for exchanging coolant between adjacent streams of coolant. To ensure a sufficiently large proportion of liquid coolant in the upper region of the fuel assembly, some of the coolant fed to the fuel assembly is passed directly into this region by means of a coolant tube. These measures - particularly in the case of boiling water reactors - ensure that the surfaces of the fuel rods themselves are still wetted with liquid coolant even in the upper region of the fuel assemblies, in which a significant proportion of the coolant has already evaporated.

The spacers which are required to guide and support the fuel rods, together with the vanes or lugs which they bear, are usually provided at intervals of approximately 0.5 m above one another and form a resistance to the streams of coolant. This resistance requires a not inconsiderable proportion of the pumping power of circulation pumps which drive the coolant. The pumping power required in known nuclear reactors is in the range of a few megawatts.

Summary of the Invention:

It is accordingly an object of the invention to provide a fuel assembly, which overcomes the above-mentioned disadvantages of the heretofore-known devices and methods of this general type and which is fitted with spacers that present only low flow

resistances yet nevertheless generate a sufficiently powerful swirl in the streams of coolant.

With the foregoing and other objects in view there is provided, in accordance with the invention, a fuel assembly for a nuclear reactor in a nuclear power plant, comprising:

a plurality of spacers;

a multiplicity of fuel rods extending in a longitudinal direction through the spacers;

the fuel rods defining a passage for a flow of coolant thereinbetween; and

at least one of the spacers carrying a vane disposed to impart a swirl impulse to the flow of coolant, the vane being curved in the longitudinal direction and in a transverse direction and having a shape resembling a spoon or a paddle.

In other words, the objects of the invention are achieved in that the vanes which are supported by the spacer are curved in both the longitudinal direction and the transverse direction and are accordingly of a shape resembling a spoon or a paddle.

The invention is based on the consideration that in fuel assemblies holding nuclear fuel, means for exerting a swirl

impulse on a stream of coolant which are provided at the spacer in a wide range of fuel rods guided through spacers for use in a nuclear reactor constitute the minimum possible flow resistance to the coolant if their shape means that with virtually all cross sections there is an area moment of inertia which is so large that even a simple vane made from thin sheet metal is sufficiently rigid.

Surprisingly, it is specifically the spoon- or paddle-like shape of the or each vane which allows the flow resistance of the spacer to be reduced in two respects. Firstly, this shape, on account of the high rigidity of the vane, makes it possible simply to use thin starting material for the spacers. Secondly, this shape allows optimized efficiency of the vane itself such that it acts as a turbine blade in the flow of coolant.

A particularly expedient optimization measure consists in this shape of the vane continuing as far as its root located in the spacer. In this case, the area moment of inertia of the cross sections of the vane reaches a maximum in the region where it emerges from the spacer.

In an advantageous configuration, to set the area moments of inertia of the cross sections of the spoon- or paddle-like shape of the vane, during production of the vane the material

used is stretched and/or compressed in more than one direction. Moreover, firstly the width of the vane at its free end should preferably be half as wide as at its root. Secondly, the free length of the vane should be approximately double the width at its root. The or each vane and a web of the spacer which bears it advantageously form a single workpiece. In this case, the shape of the vane continues into the spacer over a distance corresponding to 0.5 to 1.0 times the free length of the vane. Furthermore, an opening is expediently provided beneath the root of the vane in the direction of the longitudinal axis of the vane. This opening is used to connect cells in the spacer which are separated from one another by the web which bears the vane.

The vane, or each vane, is bent out of the plane of the web which carries it, preferably by up to 45°, into the passage for the stream of coolant, the stream of coolant impinging on the concave side of the vane. In this case, a longitudinal axis of the vane expediently forms an acute angle with a longitudinal edge of the web on the side which faces an adjacent intersection with another web.

Two webs which cross one another should in each case bear one vane on both sides of the intersection. In this case, all the vanes which adjoin the same intersection should act on the stream of coolant in the same direction, while the vanes of

intersections which adjoin one another produce oppositely directed swirl impulses. The vanes are preferably supported by the webs of the spacer on the side via which the coolant flows out. In this case, the webs are formed by sleeves which are connected to one another at their longitudinal sides and each of which surrounds one fuel rod.

The advantages which are achieved by the invention consist in particular in the fact that the use of, for example, only 0.2 mm thick metal sheet - instead of the approximately 0.4 mm thick metal sheet which has hitherto been customary - which is made possible by the high inherent rigidity of the vanes, in combination with the optimized shape of the vane, reduces the power required to drive a circulation pump by a few percent and accordingly significantly increases the efficiency of the reactor.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a fuel assembly, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

Brief Description of the Drawings:

Fig. 1 is a schematic diagram illustrating a boiling water reactor with a steam turbine, a generator, and a condenser;

Fig. 2 is a partly broken-away side elevation of a fuel assembly;

Figs. 3 and 4 are sections of webs of a spacer from the fuel assembly in their natural size;

Fig. 5 is a perspective detail of a web with a vane in a highly enlarged illustration; and

Figs. 6 to 8 are cross sections taken through the vane of Fig. 5 along the lines VI-VI, VII-VII, and VIII-VIII, respectively.

Description of the Preferred Embodiments:

Referring now to the figures of the drawing in detail and first, particularly, to Fig. 1 thereof, there is shown a

boiling water nuclear reactor (BWR) with fuel assemblies or fuel elements 2 and control rods 3 disposed in a pressure vessel 1. The control rods 3 can be moved into and out of spaces between the fuel assemblies 2 from below in order to control the neutron flux in the reactor core. Both the fuel assemblies 2 and the control rods 3 are cooled by water that flows through the reactor core from the bottom upward as coolant K. The water simultaneously serves as a moderator for the neutron flux by decelerating the neutrons down to a velocity range in which they can be trapped by atom nuclei of the nuclear fuel.

The coolant K is heated as it passes along and through the fuel assemblies 2 and in the process is partially evaporated. The steam thus formed is fed to a steam turbine 5 via a live steam line 4. The steam turbine 5 drives a generator 6. Used steam emerging from the steam turbine 5 condenses in a condenser 7 to form condensate which is fed back by a feed water pump 8 through a feed water line 9 into the upper part of the pressure vessel 1.

Coolant K which has not evaporated on the path along the fuel assemblies 2 flows back down through a non-illustrated ring circuit which surrounds the reactor core, and is fed by coolant pumps 10 into the space below the reactor core. In

newer reactors, the coolant pump 10 is arranged directly in the ring circuit within the pressure vessel 1.

Fig. 2 shows a more detailed illustration of one of the fuel assemblies 2. A fuel assembly root 11 positions the fuel assembly 2 by means of a fitting member 12 onto a lower tie plate. The assembly root 11 has inflow openings 13, 14 for the coolant K. A fuel element casing or channel 15 surrounds a bundle of fuel rods 16 over their entire length, is supported at the bottom on the fuel assembly root 11 and in its upper end bears a fuel assembly head, of which only a handle 17 projects upward out of the fuel assembly casing 15. The fuel rods 16, which are approximately 4.5 m long and approximately 11 mm thick, are filled with pelleted nuclear fuel. Spacers 18 are used to stabilize and guide the bundle of fuel rods 16 and are in turn supported laterally against the fuel assembly channel 15 from the inside; by way of example, ten of these spacers, generally at approximately regular intervals above one another, hold the fuel rods 16 together. Some of the possible fuel rod positions are provided with holding rods 19 instead of fuel rods 16 and absorb tensile forces which occur in the fuel assembly 2 between the fuel assembly root 11 and the fuel assembly head.

A casing of the spacer 18, which can be seen in Fig. 2, comprises a grid of webs 20 and 21, which are illustrated in

their natural size in excerpt form in Figs. 3 and 4. The webs 20 and 21 differ substantially only by the fact that mounting slots 22 are provided at the bottom in the web 20 while mounting slots 23 which are open at the top are provided in the web 21. In the exemplary embodiment illustrated, in each case nine webs 20, which are parallel to one another, are introduced from the top into nine webs 21, which are likewise parallel to one another and are arranged at right angles to the webs 20, in a comb-like manner, moving into the mounting slots 23 in such a manner that their own mounting slots 22 flank the lower halves of the webs 21. A grid which is formed in this way forms mesh openings which are square in cross section and each of which receives a fuel rod 16 or a holding rod 19 and, in a manner which is not illustrated, centers it by means of fixed and flexible support means. The holding rods 19 and fuel rods 16 guided by the grid comprising the webs 20 and 21 form cooling passages with a cruciform cross section. The intersections of the webs 20 and 21 in this case lie in the center of a cruciform passage cross section of this type.

On their top edges 24 and 25, the webs 20 and 21 bear vanes 26 which are approximately twice as long as they are wide and which are bent out of or into the plane of the drawing by up to 45°. The longitudinal axis of a vane 26 in each case forms an acute angle with that section of the edge 24 or 25 which bears it which adjoins an intersection between the webs 20 and

21. At its free end, the vane 26 has a reduced width, preferably a width which is reduced by half, compared to its width at its root 26a (Fig. 5). In this case, on a single web 20 or 21 vanes 26 which are associated with the same intersection between the webs 20 and 21 are bent in opposite directions, and the vanes 26 which are associated with the same mesh opening in the grid are bent in the same direction. In this way, when the grid formed by the webs 20 and 21 is seen from above, at each intersection all four vanes are bent either in the clockwise or counterclockwise direction, opposite bending directions being effected at intersections which respectively adjoin one another. As a result, at adjacent intersections the vanes generate oppositely directed swirl impulses in the stream of coolant flowing past them.

In each of the webs 20 and 21 there is, at least beneath each vane 26, an opening 27 which connects adjacent mesh openings in the grid formed by the webs 20 and 21 to one another. These openings 27 make it possible to produce transverse components in the stream of coolant directed substantially parallel to the fuel rods 16 and in this way reduce the effects of the residual flow resistance of the vanes 26.

As shown in Figs. 5 to 8, the vanes 26 are curved in both the longitudinal direction and the transverse direction, irrespective of their deviation out of the plane of the webs

20 and 21. They are therefore in the shape of a spoon or a paddle; while they are being shaped, they are stretched and/or compressed in more than one direction. This shape means that the area moments of inertia of both the cross sections lying parallel to the longitudinal axis of the vane 26 and the cross sections lying at right angles to this longitudinal axis are so high that forces which occur during normal operation do not deform the vanes 26 on their own and overall cannot make them deviate significantly in any direction. As a result, forces which are exerted on the concave side of the vane 26 by the stream of coolant are unable to make the vane 26 oscillate with significant amplitudes even if the webs 20 and 21 - like the vanes 26 - consist of a single piece of metal sheet which is only 0.2 mm thick. These advantages are promoted further as a result of the spoon-like or paddle-like shape continuing into the web 20 or 21 over 0.5 to 1 times the length of the vane 26. In this case, the area moment of inertia of the cross sections of the vane 26 in the region where they are attached to the web 20 or 21 reaches a maximum at the height of the edge 24 or 25.

A grid provided in the spacer 18 may also be composed of sleeves which are round in cross section instead of webs 20 and 21 which cross one another at right angles. In this case, one sleeve is required for each grid mesh opening, bearing four vanes 26 per sleeve instead of the grid described above.

The invention can also be used in a corresponding way on the fuel assemblies, which do not have any fuel assembly channels, of pressurized water reactors (PWRs).